A user's guide to MASTARe 2.0

MASTARe2.0 is compatible with Windows 95, 98, NT4, 2000, & XP. Nevertheless, some Windows display setups may be source of corrupted Mastar graphics. If this is the case, we advise to

- setup standard fonts in the Properties/Appearance window (available with the right-button click on the desktop Windows screen)
- adjust the screen resolution to 1024x768 pixels or more in the Properties/Settings window (available with the right-button click on the desktop Windows screen)

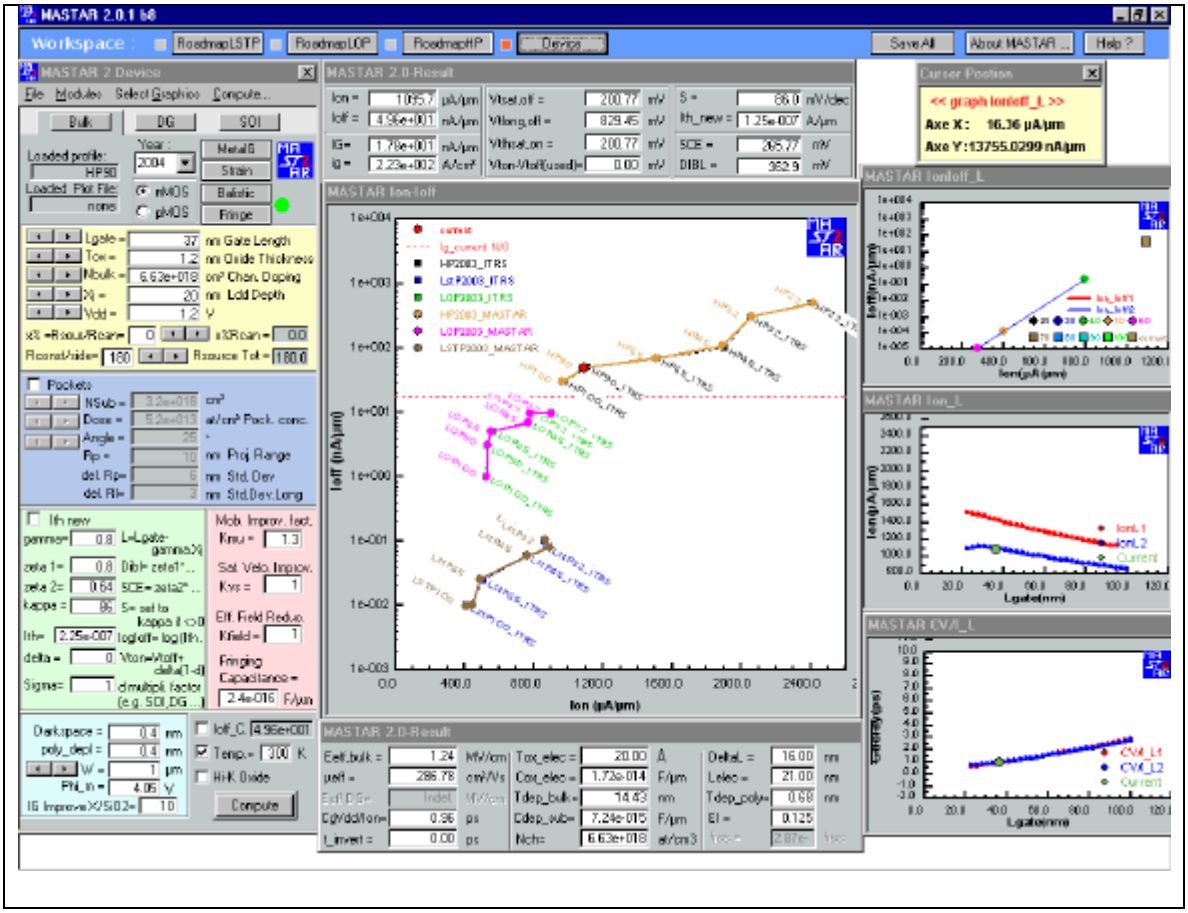


Figure 1: Mastar 2.0 : global view of the workspace "Device".

The philosophy of MASTAR

Mastar 2.0 is a computing tool especially conceived for the calculation of the electrical characteristics of advanced CMOS devices such as planar bulk transistors, Double Gate (DG) or Silicon On Isolator (SOI) devices. The calculation is based on

analytical drift diffusion equations, which depend directly on the major technological parameters, such as gate length, channel doping, oxide thickness, etc. This application allows the user to evaluate *immediately* the impact of these technological parameters on the main transistor characteristics such as the threshold behavior, performance values or time delay. Moreover, the influence of "physical" secondary parameters such as mobility, poly depletion and dark space can be visualized giving a deep insight in the physics of CMOS devices. Due to a possible limited validity of the drift diffusion models with respect to very short devices, the MASTAR predictions should be considered as "worst case".

The installation of the MASTAR 2.0 package

Mastar 2.0 is delivered as a compressed package of files. After reception, please create a MASTAR folder where you copy the whole stack of files. For execution, just click on the MASTAR2.0.exe file. Whenever you create or modify files (e. g. *profile* files, *plot* files or result files) within MASTAR 2.0, these files will be generated or updated in this current folder. In an analogous way, profile or plot files can only be loaded if they are located in this current folder. So make sure that they haven't been moved to a different folder.

A quick view on MASTAR's principal functionalities

Having started Mastar 2.0 the user will be asked to choose between the workspaces "Device" and "Roadmap". The workspace "Device" is useful for the understanding of the characteristics and of the physics of one given technology whereas the menu Roadmap is especially conceived for constructing CMOS roadmaps composed of different "technology flavors" (Bulk, SOI, DG, etc) per node.

The choice of "technology flavor" (**by selection of Bulk, SOI or DG buttons**) affects automatically the model of SCE and DIBL, and some other parameters :

- **Button Bulk**:

$$EI \equiv \left(1+\frac{X_j^{\,2}}{L_{el}^{\,2}}\right)\frac{T_{ox\_el}}{L_{el}}\frac{T_{dep}}{L_{el}}$$

$$SCE \approx 2.0\times\Phi_d\times EI$$

$$DIBL \approx 2.5\times V_{ds}\times EI$$

for other equations see Appendix B

1. **Xj =entry** and **Tdep =bulk theory**
2. **Kfield**=1 (effective field reduction factor)
3. **Kappa**=0 (if Kappa=0 then bulk theory is used for calculation of the subthreshold slope coefficient S– see equations, if Kappa<>0 then S=Kappa)
4. **Kd**=1 (if Kd=1 then Bulk theory is used for calculation of the body-effect coefficient Kd- see equations)

- **Button SOI** (this button corresponds to FD SOI technology):
  In the same equations as for Bulk, the following substitutions are made automatically:

  1. **Xj = Tsi** and **Tdep = Tsi** (Tsi becomes an entry instead of Xj)
  2. **Kfield**=0.5 (effective field reduction factor)
  3. **Kappa**=75 (to set the subthreshold slope value to 75mV/dec, if Kappa=0 then bulk theory is used – see equations, if Kappa<>0 then S=Kappa)
  4. **Kd**=0.5 (to reduce the body-effect coefficient by factor 2, if Kd=1 then Bulk theory is used - see equations)

- **Button DG** (this button corresponds to symmetrical Double Gate technology – also called GAA – gate-all-around) :
  In the same equations as for Bulk, the following substitutions are made automatically:

  1. **Xj = Tsi/2** and **Tdep = Tsi/2** (Tsi becomes an entry instead of Xj)
  2. **Kfield**=0.5 (effective field reduction factor)
  3. **Kappa**=65 (to set the subthreshold slope value to 75mV/dec, if Kappa=0 then bulk theory is used – see equations, if Kappa<>0 then S=Kappa)
  4. **Kd**=0 (to reduce the body-effect coefficient by factor 2, if Kd=1 then Bulk theory is used - see equations)

Whatever the choice of "technology flavor" , the user can also evaluate the impact of the following "technology boosters" by pressing a corresponding button or by setting manually the desired value of the corresponding parameter:

- **Button "Strain"**
  - **Evaluation of high mobility materials** by setting **Kmu** parameter (default values: **standard=1, boosted=2**) that has the effect of multiplying the universal mobility by Kmu (long channel)
- **Button "Ballistic"**
  - higher carrier saturation velocity by setting **Kvs**>1(it may be used to mimic the **ballistic transport** with all the precautions this implies !) – default values: **standard=1, boosted=1.3**
- **Button "metallic gate"**
  - Simulation of the metallic gate by setting **Poly_depl** =0 (default values: **standard=4 for NMOS & 6 for PMOS, boosted=0**)
- **Button "Fring"**
  - Simulation of the effect of reduced gate fringing/overlap capacitance by setting **Fring_Capa** (default values: **standard=2.4e-16F/µm, boosted=1.3e-16 F/µm**)

The default values of the parameters (Kfield, Kappa, Kd, Kmu, Kvs MetalGate and FringCapa) can be set by the user by modifying the "**Preferences**" file (see *Figure 2*) in the "File" menu in the working space "Devices". These default values will be used when pressing a "technology flavor" button or a "technology booster" button. It has to be noted that in addition to changing the default values in the "Preferences" file, the user can impose manually any arbitrary value of any parameter by just modifying its value in the corresponding field of both "Device" and "Roadmap" workspace.

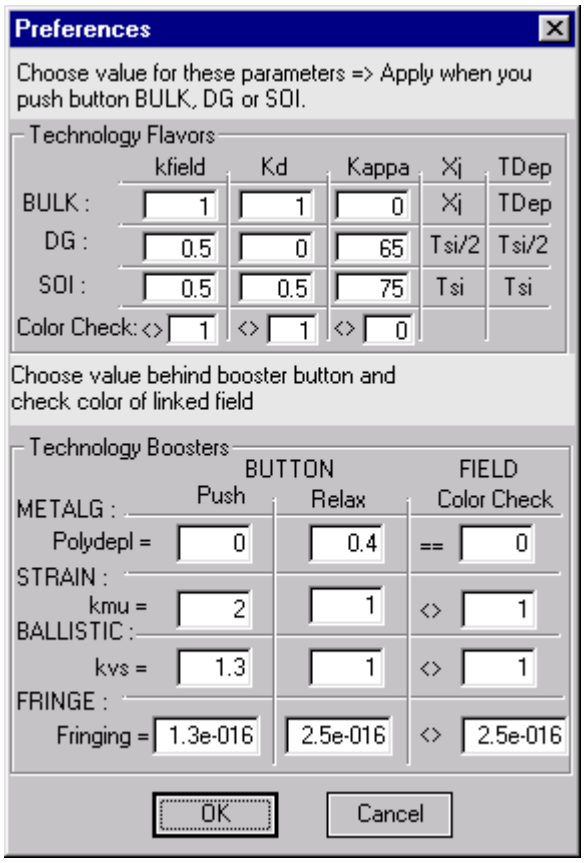


Figure 2. Content of the "Preferences" file.

CAUTION : the values of Kfield, Kd, Kappa, Poly_dep, Kmu, Kvs and Fring used in the ITRS 2003 profiles take often some intermediate values between the standard and boosted ones. This results from how they were defined in the PIDS Excel spread-sheet – we have used the same values for having a full compatibility between the two tools. The consequence of that is, however, that once having loaded for example the HP22nm node (that is defined as DG) and pushing the DG button you will not obtain the same results. The good habit is thus to save an unaltered copy of the package as-sent before all manipulation, so as to be able to retrieve the original profiles in case of un-cautious over-writing.

The working space "Devices"

The main dialogue window: a global view

After clicking on the "Devices" button the main dialogue window will appear displaying the principal technological parameters and computational choices. These parameters can be directly entered or modified starting from a given value using the adjacent buttons. The input parameters are listed and explained in Table 1-5.

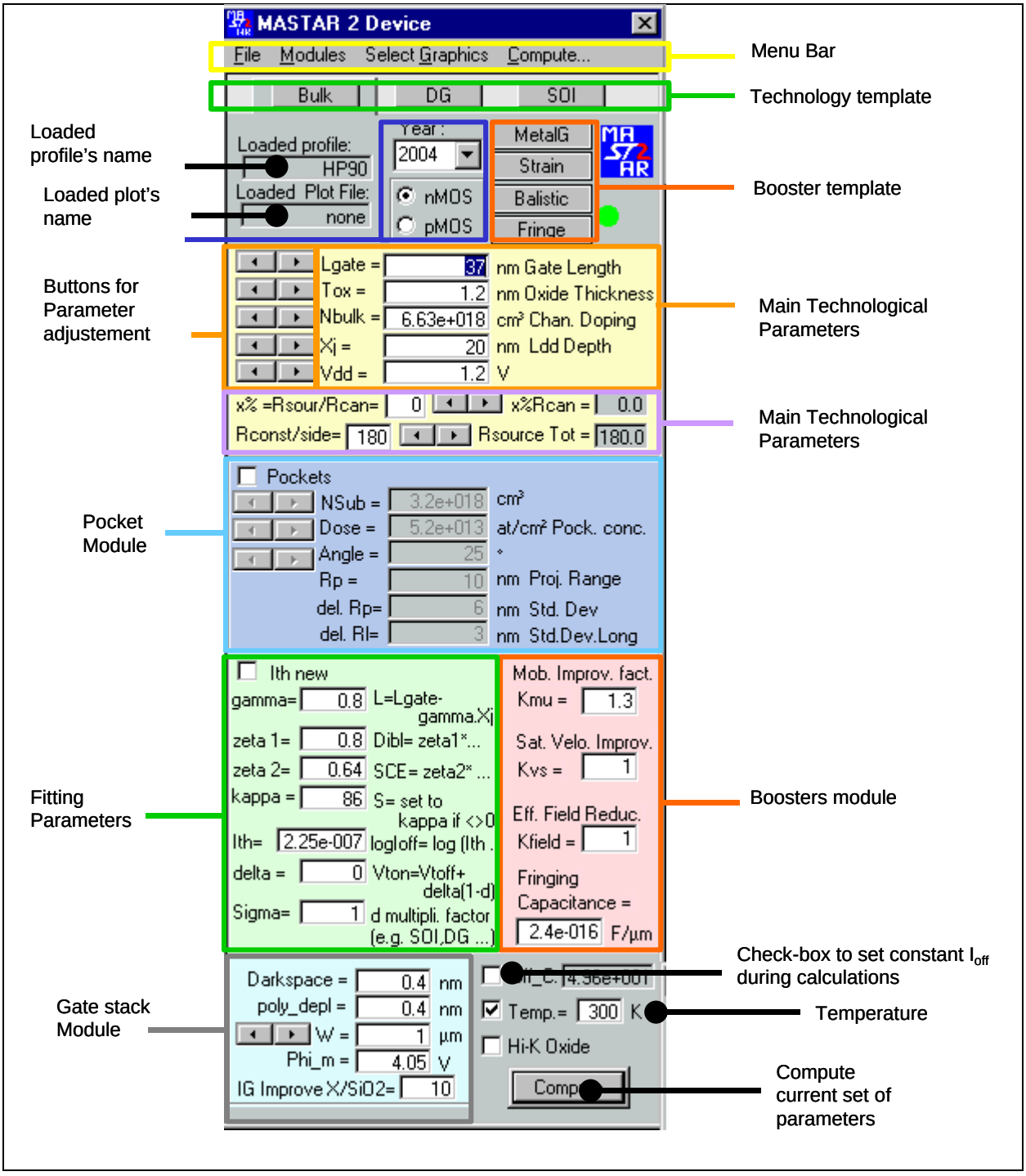


Figure 3: The MASTAR main dialogue window of the Devices application. The content of this window constitutes what is called (and can be saved as) the CMOS node profile.

The window contains furthermore modules for the computation of the series resistance, the parasitic effects like DIBL and SCE, the carrier mobility, the EOT

correction by poly-depletion and quantum effects as well as pocket doping. The sub-modules are activated when clicking on the corresponding check boxes.

Parameter	**Description**	**Dimension**
L_{gate}	*Physical* Gate Length	*nm*
T_{ox}	*Physical* Gate Oxide Thickness	*nm*
N_{ch}	Channel Doping (w/o Pockets)	atm/cm^{-3}
X_j	LDD Junction Depth	*nm*
V_{dd}	Operation Voltage (Gate and Drain Voltage)	*V*
Dark Space	*EOT* of the Charge Free Space at the Channel Interface	*Å*
Poly Depl	*EOT* of the Depletion Zone of the Poly-Si	*Å*

Table 1: Description of the main input parameters from the main dialogue window.

Parameter	**Description**	**Dimension**
x	Percentage of Channel Resistance $R_{ch} = V_{dd}/I_{on}$	*none*
$R_{const}/side$	Constant Series Resistance (Source)	*W*
R_{source_tot}	Resulting total Source Resistance	*W*

Table 2: Parameters used in the Resistance Module.

The Booster Template

The buttons in this field allow the user to switch one or several performance boosters, which are Strained Silicon, Metal Gate, Ballistic Transport and Reduced Fringing Capacitance. Once the performance booster is activated, a set of predefined parameters – accessible by the Preference option of the File Menu - is loaded. In order to trace the changes, the parameter modifications with respect to the situation without boosters are highlighted in the main window. The Table below summarizes the effect of each button. When pressing the button again, the booster will be switched off and the parameters are set to their default values.

Button	**Action/Booster value**
Metal Gate	Poly_depl=0
Strain Silicon	Kmu=2
Ballistic	Kvsat=1.3
Fringe	Cfringe = 1.3e16

Table 3 : Default value of booster when using the template buttons

The main dialogue window: the submodules

The module ***Pockets*** enables to take into account a non-uniform lateral doping distribution in the channel due to pocket or halo implant. This is very useful to fit experimental $V_{th}(L_{gate})$ curves. To activate this module, click on the corresponding check box. The adjustable parameters are shown in the Table 4. For a physical interpretation of these parameters, please refer to the annex A. Pressing the *Compute*-button will update the calculations.

Parameter	**Description**	**Dimension**	**Default**
C_{poches}	Pocket Implantation Dose	atm/cm^2	*2e13*
Angle	Pocket Implantation Angle	*degrees*	*25*

R_p	Implantation Depth	*nm*	*65*
del.R_p	Vertical Pocket Extension	*nm*	*23*
del. R_l	Lateral Pocket Extension	*nm*	*32*

Table 4: Parameters used in the Pocket Module, see Annex A for more details on the pocket-related parameters.

The ***Mobility*** module contains several scaling factors or performance boosters for the effective mobility, the saturation velocity and the effective field, which might be appropriate in the case of advanced CMOS architectures such as strained Si, fully depleted devices, etc.

Parameter	**Description**	**Dimension**
k_{mu}	Scaling Factor for the effective Mobility: $\mu' = k_{mu} * \mu$	none
k_{vs}	Scaling Factor for the eff. Saturation Velocity: $v_{sat} = k_{vs} * v_{sat}$	none
kfield	Reduction factor of the Eeff for advanced archtitectures	none

Table 5: Description of the parameters used in the mobility computation.

In the ***user defined settings*** module, several parameters can be modified concerning the calculation of SCE, DIBL, S and Ioff. The default values have been adjusted to fit the most recent planar CMOS technologies (CMOS 90 and 65 nm) and literature data (IEDM'02 and VLSI '02). We recommend you to save a back-up copy of MASTAR, that will allow you to recover the default values of all parameters in case of modification.

Parameter	**Description**	**Dimension**	**Default**
Gamma	Scaling Factor for the Lateral Diffusion: $L_{elec}=L_{gate}$-$gamma_*X_j$	*none*	*0.8*
Zeta1	Scaling Factor for the *DIBL* (*Drain Induced Barrier Lowering*)	*none*	*0.8*
Zeta2	Scaling Factor for the *SCE* (*Short Channel Effect*)	*none*	*0.64*
Kappa	If the value is not 0, S takes the entered value	*mV/dec*	*0*
I_{th}	I_d at the threshold voltage used to calculate *S* I_{thnew} activate sthe doping dependance of ith calculation.	*A*	*5e-7 A*
delta	Shift between V_{th} *"on"* and V_{th} *"off"*	*V*	*0.03*
Kd	Reduction factor of the d-coefficient=body-effect for SOI and DG, if Kd=1 then the Bulk theoretical value of d is used	*none*	*1*

Table 6: Description of the user defined settings.

A special feature is the ***button Ioff_c***, which is located in the lower right part of the main dialogue window. When this button is activated, the Nbulk value will appear gray. Indeed, the bulk doping (and thus the threshold voltage) will be automatically adjusted at a level, which gives the previously entered constant Ioff-value. This feature is very useful for the evaluation of technological options as you can get rid of threshold variation effects.

The main dialogue window: The Menu Bar

On the menu bar several submenus are accessible: the ***File*** menu enables the creation and modification of *profiles* (corresponding to a set of technological input

parameters) and *plot files* (containing sets of performance values). Via the ***Modules*** menu it is possible to access to secondary and optional technological parameters. The ***Graph*** menu enables to modify the data selection and their presentation in the main graphics. Finally, the ***Compute*** menu allows the user to update the secondary graphics. Most of these functions can be equally accessed placing the cursor on the object you want to to modify and clicking on the right mouse button.

The main output windows: numerical values and the Ion-Ioff graphics

The calculations are executed via the *Compute* button from the main dialogue window. The principal electrical characteristics will be displayed numerically in the upper output window named *MASTAR 2.0 Result*. The lower window gives access to secondary engineering parameters.

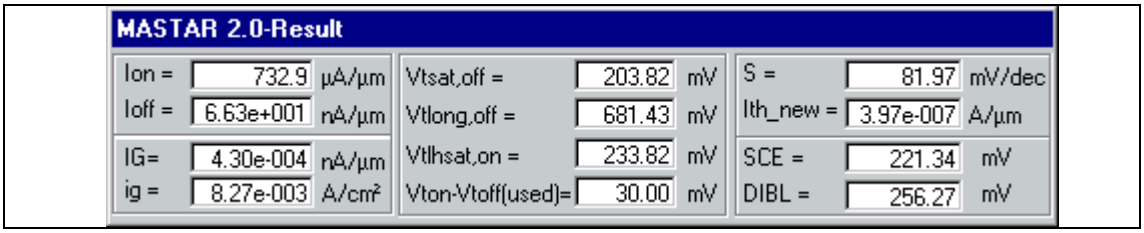


Figure 4: The upper *output window* MASTAR 2.0 *Results.*

Output Parameter	**Description**	**Dimension**
I_{on}	Drain Current for $V_{gate}= V_{drain}=V_{dd}$	*µA/µm*
I_{off}	Channel Leakage Current for $V_{gate}= 0$ *and* $V_{drain}=V_{dd}$	*nA/µm*
I_G	"off state"-Gate Leakage Current through the Drain/Gate Overlap ($V_{gate}= 0$ *and* $V_{drain}=V_{dd}$)	*nA/µm*
I_g	Capacitor-like Gate Leakage Current ($V_{gate} = V_{dd}$)	A/cm^2
N_{ch}	Channel Doping (w/o Pockets)	atm/cm^{-3}
$V_{tsat,off}$	Saturated Threshold Voltage ($V_{gate}= V_{drain} =V_{dd}$) used for the extrapolation of I_{off}	*mV*
$V_{tLong,off}$	Saturated Threshold Voltage *for infinite gate length*	*mV*
$V_{tsat,on}$	Saturated Threshold Voltage used for the I_{on} calculation ($V_{tsat,on} > V_{tsat,off}$)	*mV*
V_{ton}-V_{toff} *(used)*	Used Shift between the two Threshold Definitions	*V*
S	Sub-threshold Slope	*mV/dec*
Ith	Current at threshold	*A/µm*
SCE	Short Channel Effect	*mV*
DIBL	Drain Induced Barrier Lowering	*mV*

Table 7: Description of the parameters *of the upper output window.*

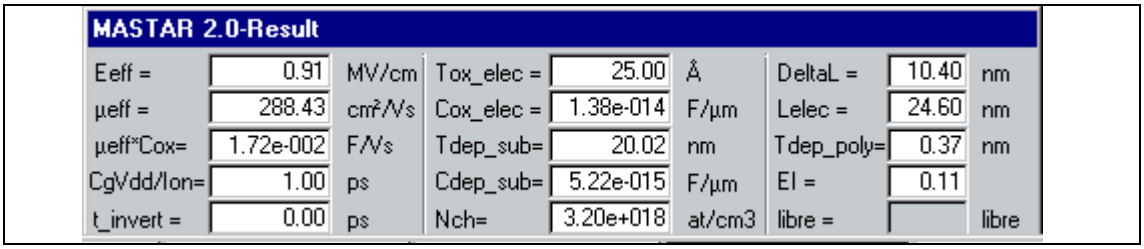


Figure 5: The output window Results2.

Output Parameter	**Description**	**Dimension**
E_{eff}	Effective Field used for the Mobility Calculation	*MV/cm*
μ_{eff}	Effective Mobility	cm^2/Vs
μC_{ox}	Capacity times Mobility	*F/Vs*
$C_g V_{dd}/I_{on}$	Gate Delay	*ps*
$T_{\_invert}$	(Inverter Delay - not yet implemented)	*ps*
T_{ox_elec}	Equivalent Oxide Thickness in Inversion	*Å*
C_{ox_elec}	Gate Capacity in Inversion	*F/µm*
T_{dep_sub}	Depletion Depth in the Substrate	*nm*
C_{dep_sub}	Depletion Capacity in the Substrate	*F/µm*
N_{ch}*	Average Channel Doping (w/ Pockets)	atm/cm^{-3}
Delta L	*DL/2* = Lateral LDD Diffusion	*nm*
L_{elec}	Electrical Gate Length: $L_{elec} = L_{gate} - DL$	*nm*
T_{dep_Poly}	Estimated Depletion Depth in the Poly-silicon	*nm*
EI	Electrostatic Integrity	

Table 8: Description of the parameters *in the lower output window.*

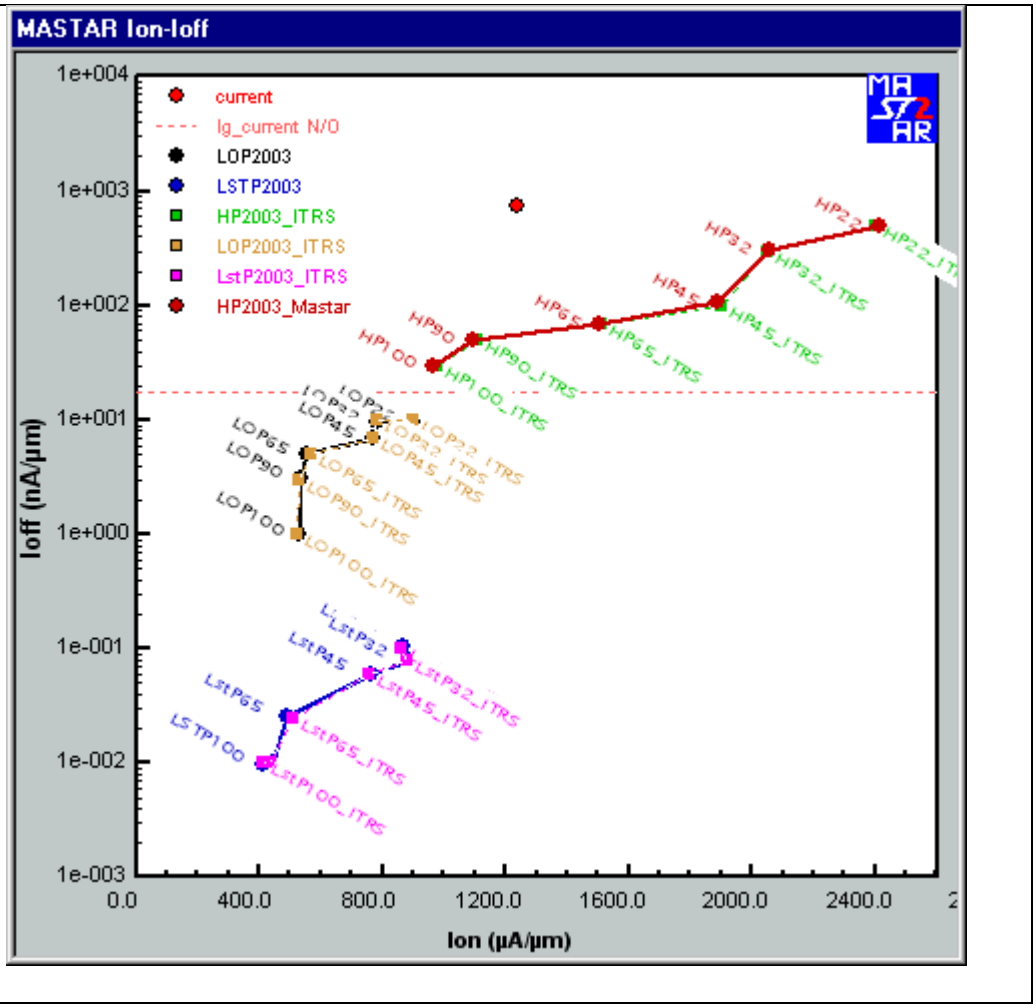


Figure 6: The principal graphical output window, the Ion-Ioff Graph displaying the "current data point" and some user selected data.

The central output window is the Ioff/Ion chart (cf. Figure 6). The current performance data point is shown as a red point in this window. In addition, predefined *plot files* - lists of Ion-Ioff values - can be added on this plot via the *Graph* Menu **or by clicking on the right mouse button** when the cursor is placed on the graph.

Some more graphics…

In addition to the central Ion-Ioff chart, MASTAR offers a variety of other useful graphical representations. These secondary graphics can be ***added on*** or ***removed*** from the work space using the ***Select Graphics*** command from the ***Graph Menu***. ***Recalculation*** of the displayed data is done via the corresponding submenu in the ***Compute Menu***. Most of these auxiliary graphics contain two curves, which can be calculated independently. This allows the user to compare current data points with previously generated data.
The following graphics are available:

Ion-Ioff Cloud:

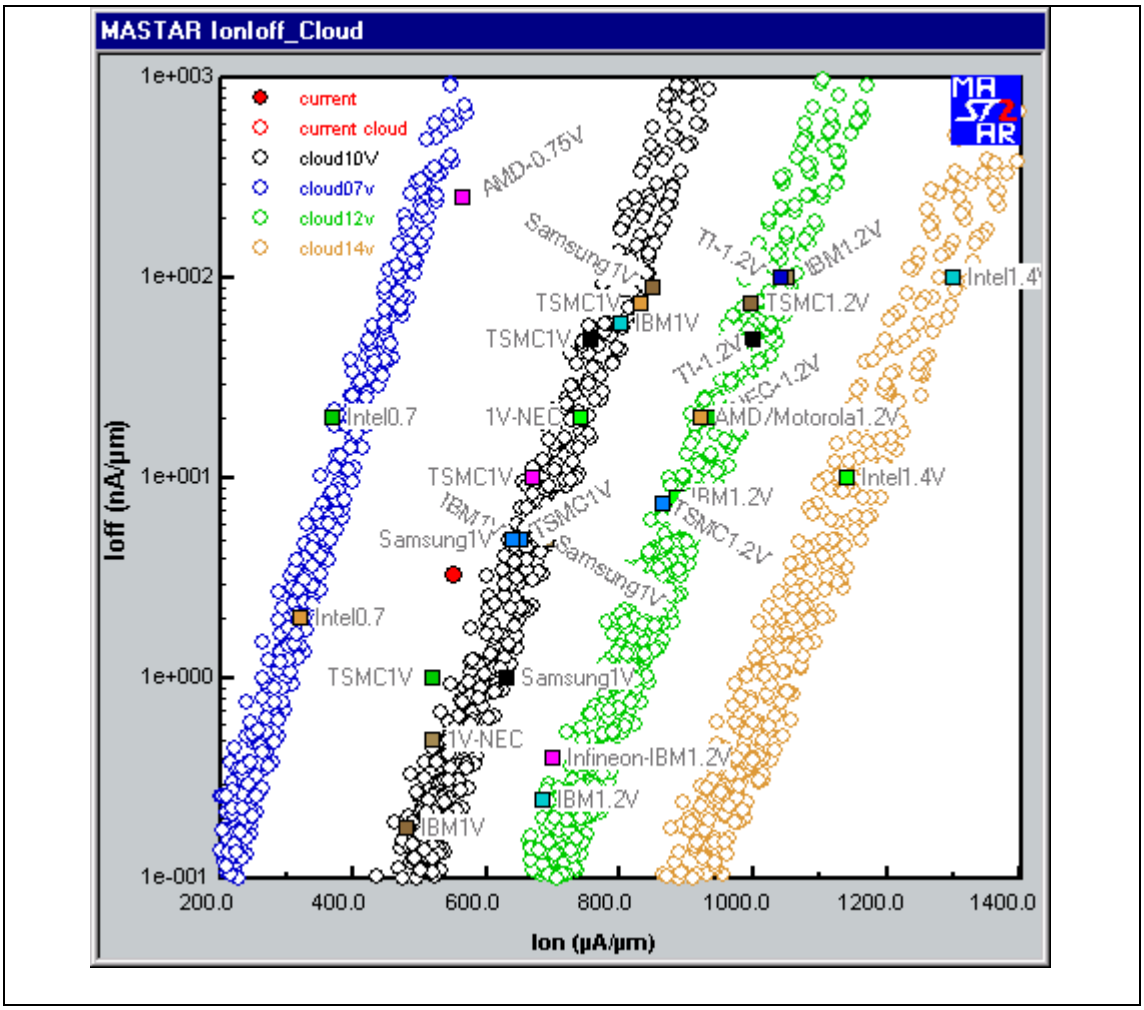


Figure 7: *The "cloud" graphics: this presentation allows the user to explore the performance domain spun up by user-defined intervals of the main technological parameters such as gate length, oxide thickness, junction depth etc and compare it with literature data.*

The ***Ion-Ioff Cloud graphics*** is a useful tool in order to explore the ***performance limits*** for a given transistor generation (cf. Figure 7). Clouds of performance data points can be generated and displayed on a Ion-Ioff graphics by simply imposing intervals and incremental steps for the main technological input parameters, such as gate length, oxide thickness, supply voltage etc.
On this graphics, you have the possibility to display in addition to the generated data user defined Ion-Ioff data, e.g. recent literature performance data, for comparison reasons. The corresponding files are stored with the extension .lpp. For more details, please refer to the "Display of Literature Data on the Ion-Ioff cloud chart" section.
When placing the cursor upon the literature performance point, a window displaying the Ion-Ioff values shows up.
The set of parameters, on which the cloud generation is based on, can be visualized when placing the cursor upon the cloud symbol in the upper left part of the graphics window: a pop-up window appears summarizing the calculation limits and steps. It is furthermore possible ton inject directly these parameters into the "Generate Ion-Ioff cloud data" window by clicking on the triangular button inside this window.

Vth(L): threshold over gate length

The ***Vth(L) graphics*** shows the dependence of the ***threshold at V_{drain}= V_{dd}*** on the physical ***gate length L_{gate}***. Two curves are presented in this graphics, which can be calculated independently allowing the user to compare the impact of the different technological input parameters. By default, the saturated threshold voltage $V_{tsat,off}$ is calculated. In order to obtain the linear threshold voltage, please choose V_{dd} = *0.1 V* in the main dialogue window.

Pocket effects on the threshold curve can be reproduced when activating the pocket window. In this case, the channel doping refers N_{ch} refers to the doping of a long channel device.

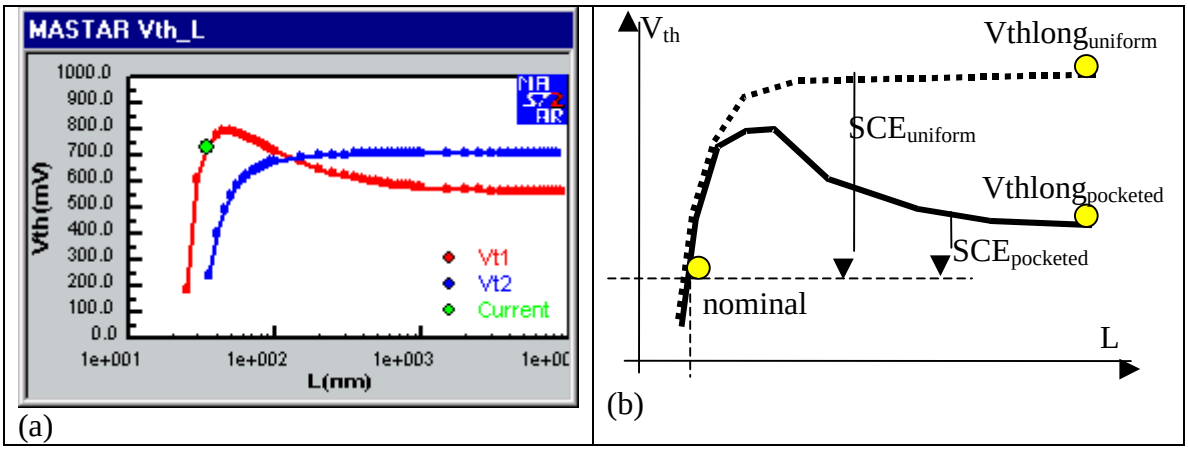


Figure 8: The Vth(L) graphics: an example of the MASTAR Vth-L plot with and without activating the pocket module.

I(L): I_{on}* over gate length @ I_{off} = *const

The ***I(L) graphics*** shows the dependence of the ***on-current I_{on}*** on the ***gate length L_{gate}***. For better comparison, ***I_{off} is kept constant*** during the calculations via a simple threshold voltage adjustment by channel doping correction.

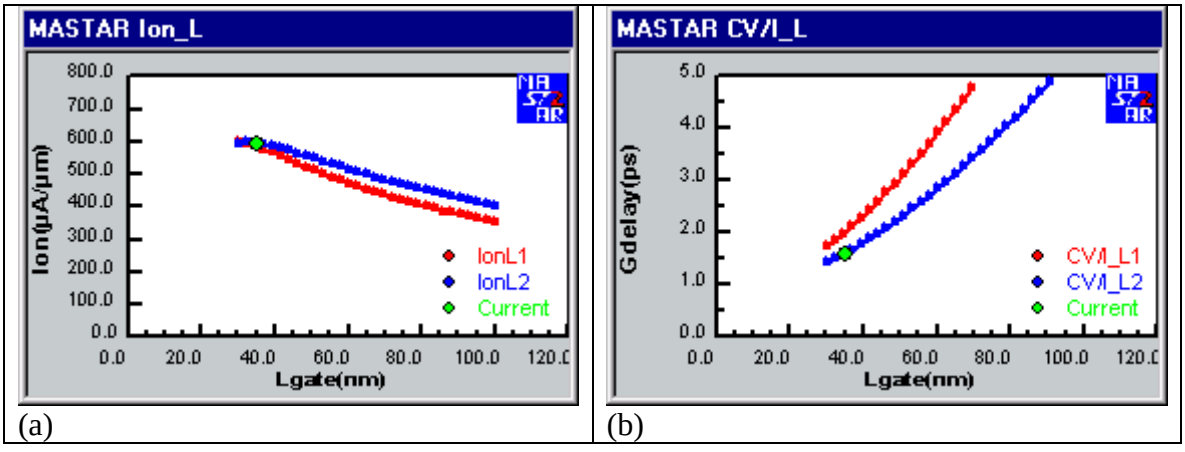


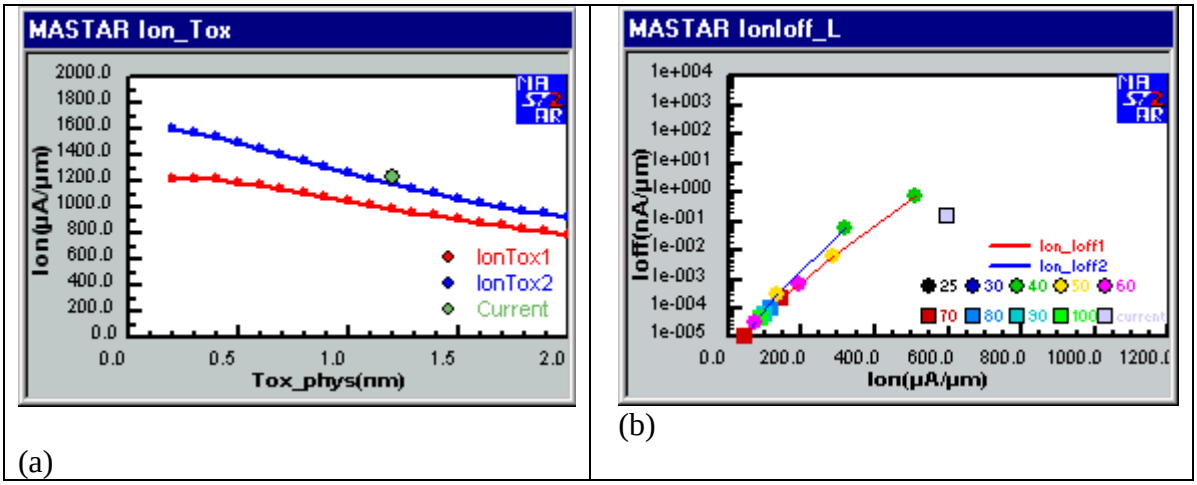
Figure 9: The Ion(L) graphics *(a)* and *the CV/I_L graphics* (b).

CV/I(L):* gate delay over gate length @ I_{off} = *const

The ***CV/I(L) graphics*** indicates the gate delay, calculated by $t = CV/I_{on}(L_{gate})$. Also for this presentation, I_{off} is automatically kept ***constant*** during the calculation to enable a better comparison.

Ion(Tox)*: I_{on} over gate oxide thickness @ I_{off} = *const

The ***Ion(Tox)*** graphics shows the evolution of the **on-current** I_{on} (at I_{off} = constant) **over the gate oxide thickness**. Two curves are presented in this graphics, which can be calculated independently.



(a) (b)

Figure 10: The Ion(Tox) graphics (a) and the Ion-Ioff(L) graphics (b).

***Ion-Ioff(L)*: performance over gate length**

The ***Ion-Ioff(L)*** graphics presents the performance data points calculated **for a set of physical gate lengths**: L_{gate} = 25, 30, 40, 50, 60, 70, 80, 90 et 100 nm.

Mastar for advanced users: description of the menus

The File menu : creation and modification of *profiles* and *plot files*

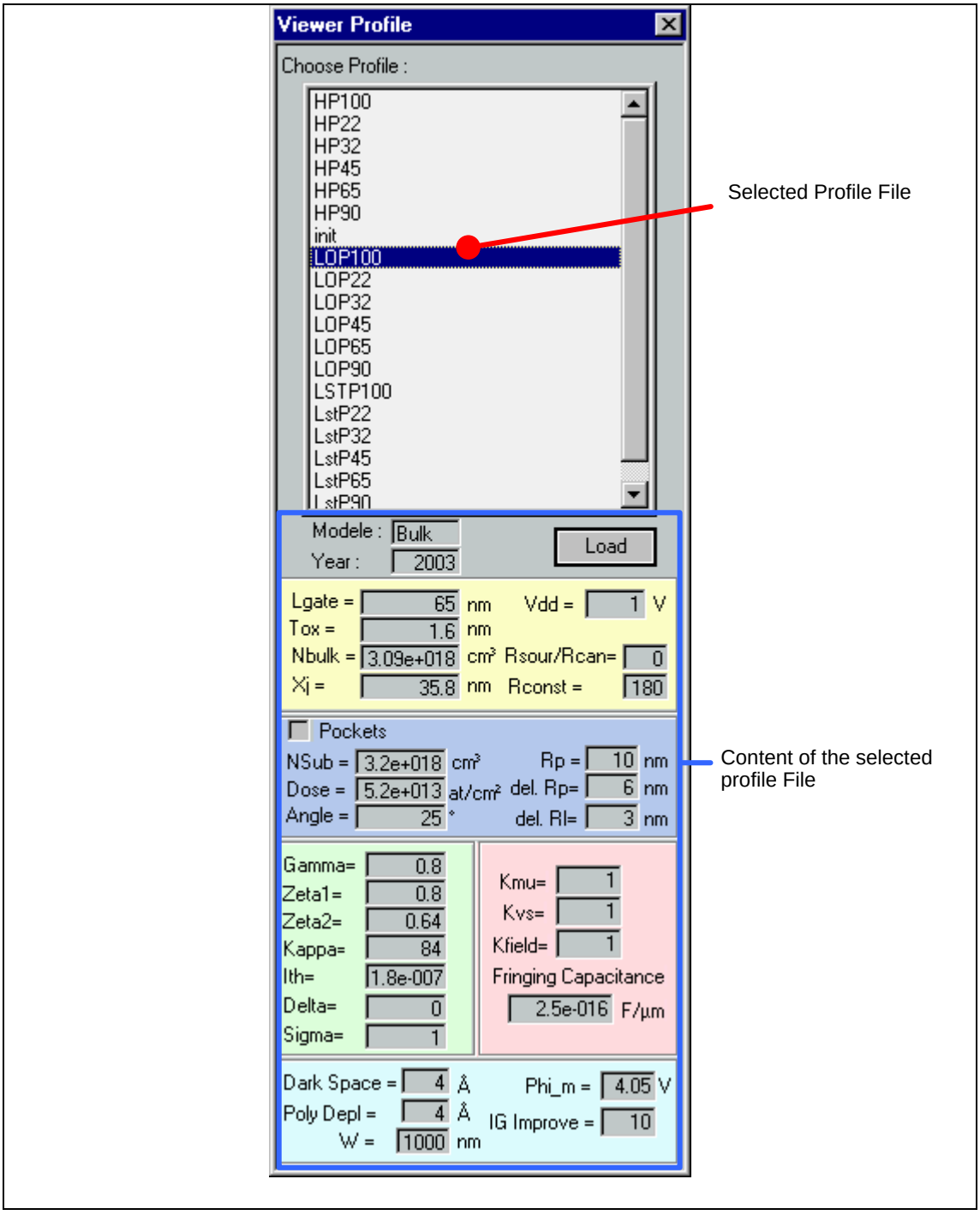


Figure 11: The Load Profile dialogue window from the File menu.

Some basic definitions…

A ***profile*** is defined as a complete ***set of input parameters*** as listed in Table 1. It can be created or loaded by the file menu. It is saved as a hidden file with the extension *.sav* and is not directly accessible to the user.

A ***plot file*** is an output file containing a ***list of Ion-Ioff values***. The extension of these files is *.plt*. ***Plot files*** *can be* ***created*** either by a text editor or ***starting from*** a set of previously defined parameter ***profiles***. Only in the latter case the ***plot file*** is ***linked*** to the underlying ***profiles***, which enables automatic modification when ***activated***. ***Plot files*** can be ***added on*** the principal ***Ion-Ioff graph***. If a *plot file* is *activated* and its

values are linked to a list of *profiles*, the Ion-Ioff values plotted on the graph are updated when modifying certain globally defined input parameters such as the mobility.

The definition of new profile files can only be done on the File menu; the loading of profiles and the manipulation of plot files can also be done using a shortcut clicking on the right mouse button when the corresponding graphics window is activated.

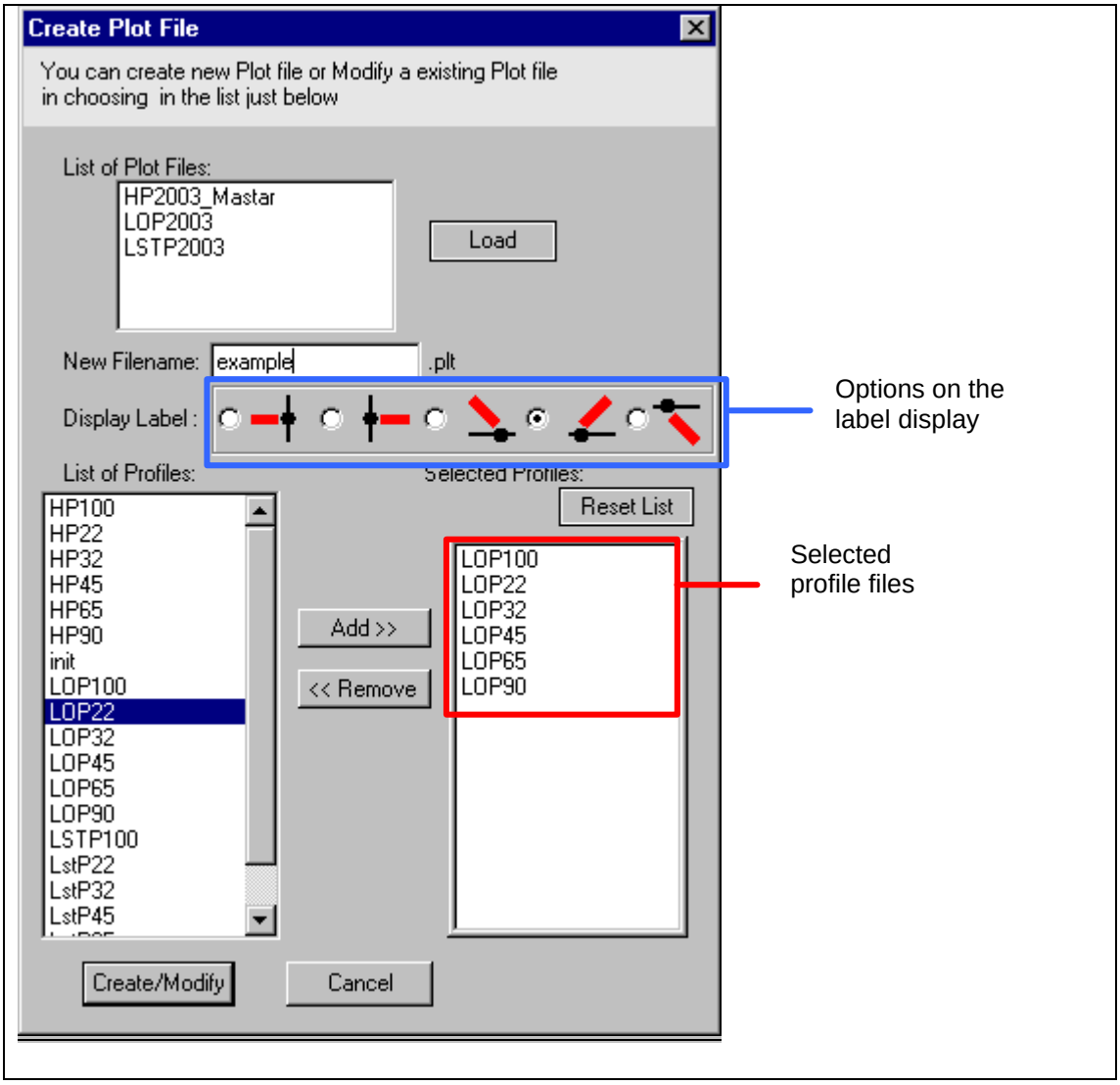


Figure 12: Dialogue window for the creation of a plot file.

Creating a *profile*

In order to save the current set of input parameters in the main dialogue window, click on the ***File*** menu and select ***Save Profile as***. A new dialogue window opens, where the profile name can be entered. If the name is already used, a warning will appear.

Loading a *profile*

A predefined set of input parameters can be loaded by selecting ***View/Load Profile*** from the ***File*** Menu. You can also access to this feature by the right mouse button directly form the graphics window. In both cases, a dialogue window opens displaying the available *profiles*. Selecting a *profile* file, its content will be visualized

in the lower part of the window. Clicking on ***Load*** will transfer the parameters into the main dialogue window. The numerical and graphical results will be updated automatically.

Saving the modifications of a *profile*

If you wish to maintain the modifications done on a previously created *profile* file, choose ***Save Profile*** from the ***File*** Menu.

Deleting a *profile*

In order to delete an existing *profile* file, use the ***Delete profile*** command from the ***File*** Menu.

Creating and modifying a *plot file*

The **first way** to create a ***plot file*** consists in creating a **text file** with the extension ***.plt*** in the current folder containing a series of Ion-Ioff values. This can be useful when you want to edit a list of literature data. Every performance data point has to be defined in the following way:

…
[*label for the specific I_{on}-I_{off} data point i*]
Ion = *I_{on} value of data point i [µA/µm]*
Ioff = *I_{off} value of data point i [nA/µm]*
[*label for the specific I_{on}-I_{off} data point j*]
…

Alternatively, a plot file can be created using the command ***Create Plot File*** from the ***File*** menu or directly by a click on the right mouse button from the graphics window. Doing this, a dialogue window appears: you can now choose the name of the *plot file* to be created. The performance data points can be chosen ***via the corresponding profiles***, which are listed on the left side of the window: select the desired *profile* and click on ***Add***. The Ion-Ioff data point calculated using these specific profile parameters is then appended to the plot file. Once the list of data points is completed just click on the ***Create***-button to save your selection of data points. In a similar way, the data selection in existing plot files can be modified. The ***graphical visualization*** on the Ion-Ioff graph is finally done via the option ***Load Plot*** (for more details refer to the corresponding paragraphs).

Other Dopings

Two parameters appear in this window: the LDD extension doping (not yet implemented) and the doping of the poly-Si of the gate stack.

Parameter	Description	Dimension	Default
Next	Dopant Concentration in the LDD extensions	*atm/cm^{-3}*	*1e20*
Npoly	Dopant Concentration in the Poly-Si of the Gate Stack	*atm/cm^{-3}*	*3e20*

Table 9: Description of the content of the Other Doping module.

The Graph Menu

This menu contains only one the function ***Select Graphics***. By this submenu the user can select the output graphics to be displayed in the workspace. Clicking on the ***Select Graphics*** command opens the corresponding dialogue window. The hidden graphics are listed on the left whereas the visible graphics appear on the right side. Select the graphics name and click on ***Add*** or ***Remove*** in order to show or hide graphics on the screen.

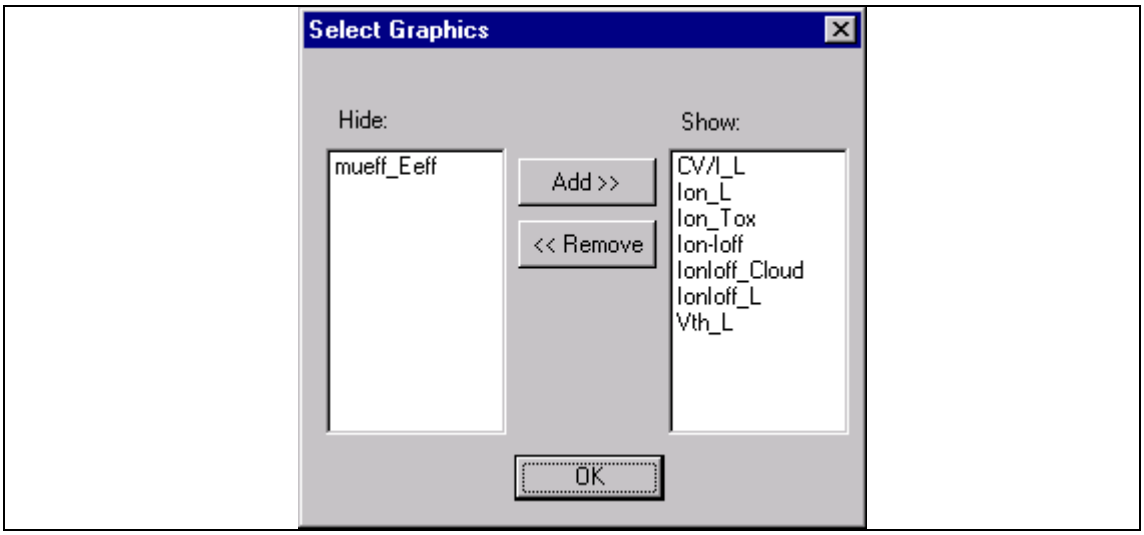


Figure 13: The Select Graphics dialogue window.

Modification of the Graphics – common features

All other graphics features are accessed directly placing the cursor on the corresponding graphics and clicking on the right button of the mouse. The following options are available on all graphics:

Modify Scale: enables to change the maximum and minimum values of the x- and y-axis and to go from linear to logarithmic scaling and vice versa

Cursor Position: a window pops up on the right upper corner of the workspace indicating the actual position of the cursor inside the selected graphics.

Hide Graph: hides the graphics.

Special features on the Ion-Ioff graphics

Load / Unload Plot : This submenu enables to ***add or remove*** series of ***data points*** on the Ion-Ioff graphics for comparison with the current data point. For this purpose, the desired data points have to be entered previously into a *plot file* with the extension *.plt. Plot files* can be created via the ***File Menu*** or by the ***Create/Modify Plot*** option directly from the graphics. If the plot file with the desired performance Ion-Ioff data points already exists just click on ***Load / Unload Plot*****:** the ***Display Plot File*** Dialogue Window is then activated. To add or remove some data points, click on the corresponding ***plot file*** in the list on the left / right side, then click on ***Add*** or ***Remove***.

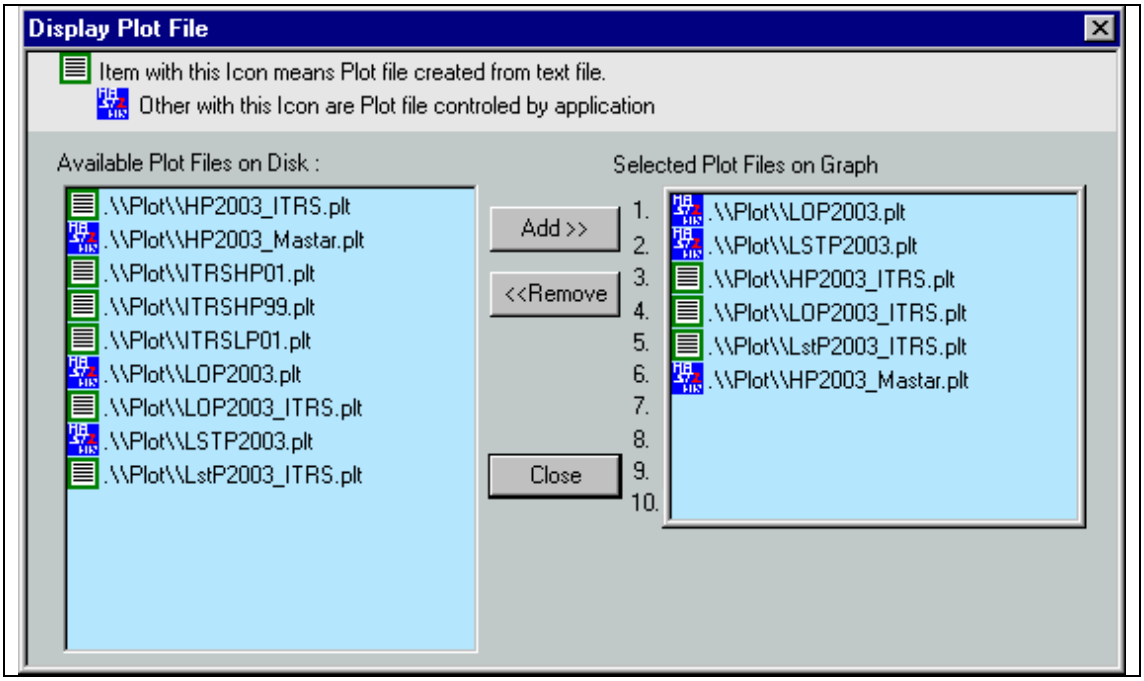


Figure 14: The Display Plot File Dialogue Window.

Create / Modify Plot: as described for the similar option in the File Menu with the only difference that it is immediately displayed on the graphics

Load Profile: as described in the File Menu

Delete Profile: as described in the File Menu

Merge ghost to actual point : sets or moves a permanent marker behind the actual position of the current data point in order to trace the changes

Delete Ghost : unsets the marker

Display Node Info: A pop-up window displaying the values is shown when you point on a data point of the graph.

Special features on the Cloud graphics

Data on Cloud: This submenu enables to ***add*** or ***remove series of data points*** on the ***Ion-Ioff Cloud graphics***, which have to be listed in data files having the specific extension *.per*. These files can be generated by the ***Ion-Ioff Data Cloud*** command from the ***Compute Menu*** or with the ***New Cloud Command*** of this submenu.

New Cloud: as described in the Compute File

Cloud Pop-up window: When placing the cursor on the cloud symbol displayed next to the cloud name on the left upper part of the window, a pop up window appears containing the parameter set, which has been used in the "Generate Ion-Ioff Cloud Data"-window to generate this data (cf. Figure 15).

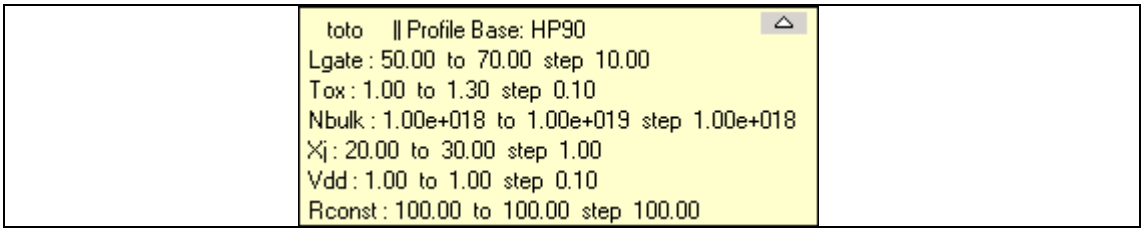

toto || Profile Base: HP90
Lgate : 50.00 to 70.00 step 10.00
Tox : 1.00 to 1.30 step 0.10
Nbulk : 1.00e+018 to 1.00e+019 step 1.00e+018
Xj : 20.00 to 30.00 step 1.00
Vdd : 1.00 to 1.00 step 0.10
Rconst : 100.00 to 100.00 step 100.00

Figure 15: Data cloud Pop-Up-Window.

The Compute Menu

This menu contains all computational commands concerning the auxiliary graphics and the cloud graphics:

Vth(L)	threshold over gate length
CV/I(L)	gate delay over gate length for I_{off} = const.
I(L)	I_{on} current over gate length for I_{off} = const.
Ion(Tox)	I_{on} current over oxide thickness for I_{off} = const.
Ion-Ioff(L)	Performance over gate length
Ion-Ioff Cloud	calculation of a performance data cloud

All…

Clicking on ***All…*** will open the ***Compute All*** window. This window allows the user to update the presented data points in all auxiliary graphics windows. To enable comparison with previously computed data, the new data will be applied *only on one (red or blue) curve* – the one selected in the dialogue window - while the second one remains unchanged. The graphics are automatically regenerated when clicking on the ***Start*** button.

Vth(L)

Via this dialogue window it is possible to update the displayed data points in the graph ***Vth(L)*** while all other auxiliary graphs remain unchanged. Again, the user can decide whether the new generated data should be applied for the red (***Vth_1***) or the blue curve (***Vth_2***). Moreover, the user can define the interval used for calculation and display (cf. Figure 16).

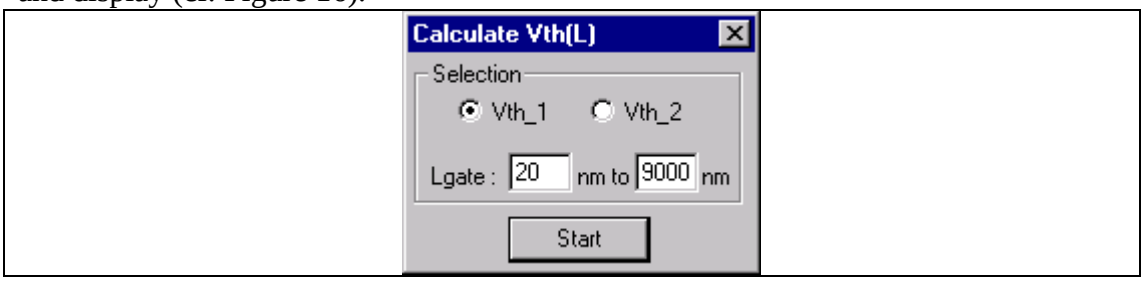


Figure 16: The Vth(L) calculation window.

CV/Ion(L) and I(L)

The submenu **CV/Ion(L) and I(L)** from the ***Compute Menu*** will open the corresponding dialogue window. The user can now select which curve he wishes to be updated and define the corresponding computational window. The ***CV/Ion(L)*** and ***I(L) graphics*** are simultaneously updated when clicking on the ***Start*** button. Note that I_{off} is kept constant during the calculation of the I_{on} values.

Ion(Tox)

This submenu allows the user to update the ***Ion(Tox) graphics***. Choose the curve by clicking on the corresponding button and update by clicking on ***Start***. Note that I_{off} is kept constant during the calculation of the I_{on} values.

Ion-Ioff(L)

In order to update the ***Ion-Ioff(L) graphics***; click on the corresponding submenu from the ***Compute*** menu. In the dialogue window, select one curve and click on ***Start*** to update the graphics. The performance data is calculated on a fixed series of gate lengths (L_{gate} = 25, 30, 40, 50, 60, 70, 80, 90 et 100 nm).

Ion-Ioff Data Cloud

The ***Ion-Ioff Cloud*** submenu opens the dialogue window called "***Generate Data Ion-Ioff Cloud***". In this window, the user will define the variation of the main technological parameters used to generate the new performance data cloud. These parameters are: L_{gate}, T_{ox}, N_{ch}, X_j, V_{dd}, R_{const}. For every parameter, the ***lower*** and the ***upper limit*** of the calculation interval must be entered as well as the ***incremental step*** of this parameter. The calculation is launched when clicking on ***Start***. The current set of calculated data points can be saved by clicking on the ***Save Data*** button. The files will then be stored in the current directory and will have the extension ***.per***. These ***.per files*** can be added on or removed from the ***Cloud Graphics*** via the ***Cloud Data Display*** function from the ***Graph menu*** or directly by a click on the right button of the mouse.

It is furthermore possible to re-inject the parameters already used for the generation of a data cloud into the "Generate Ion-Ioff cloud data": place the cursor on the cloud symbol on the left upper part of the window; a pop-up window of the underlying calculation conditions appears. By clicking on the triangular button, the "Generate Ion-Ioff cloud data " window opens containing this parameter set.

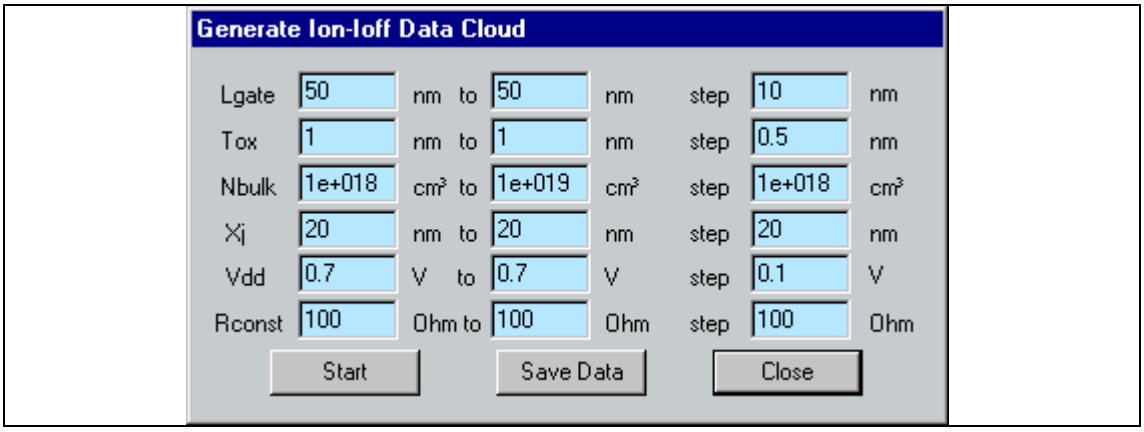

Generate Ion-Ioff Data Cloud
Lgate 50 nm to 50 nm step 10 nm
Tox 1 nm to 1 nm step 0.5 nm
Nbulk 1e+018 cm³ to 1e+019 cm³ step 1e+018 cm³
Xj 20 nm to 20 nm step 20 nm
Vdd 0.7 V to 0.7 V step 0.1 V
Rconst 100 Ohm to 100 Ohm step 100 Ohm
Start
Save Data
Close

Figure 17: The Ion-Ioff Data Cloud parameter window.

Display of Literature Data on the Ion-Ioff cloud chart

The Ion-Ioff graphics has been designed in order to enable comparisons with user defined data, e.g. performance data points from recent publications, enabling thus reverse engineering, i.e. to identify the technological options necessary to achieve these performances.
By default, MASTAR contains a file named *Literature_Perf.lpp* containing a list of recent literature values, which is loaded in the Cloud graphics window. For editing, e.g. adding / removing or selecting / deselecting data points, please click on the *right mouse button* and choose the option *Edit/Modify Literature_Perf*; the literature editor will be opened (cf. Figure 18). Every line of the text file corresponds to a data point containing the Ion-value in µA/µm, the Ioff-value in nA/µm, the label and its orientation to appear in the graphics window. All data points are distinguished by color, shape and label. Data points are deselected when two slash characters are put in front of the corresponding line. If you wish to create a new .lpp-file, please use "Save As".

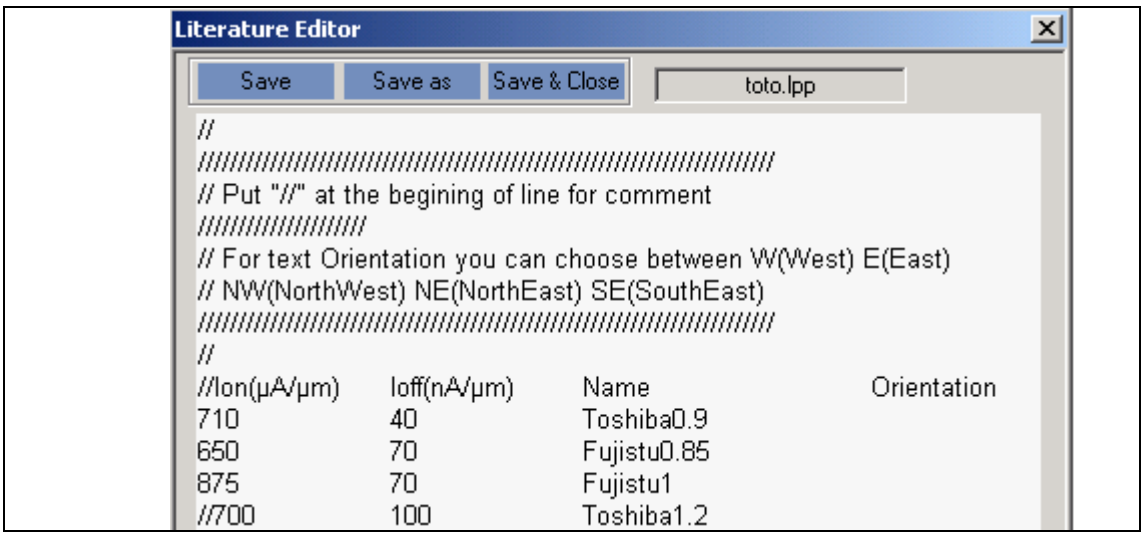


Figure 18: The Literature Editor.

Once you have created several .lpp-files you can select which one you would like to display. To do this, please use the "Change Literature_Perf"-option; the corresponding window will be opened (cf. Figure 19). If you don't wish to display any file, delete the file name, which appears in the lower box. The file itself can be suppressed using the "Suppress"-button from your keyboard. Please remind that only one file can be shown at once and that the last file will be automatically reloaded when restarting MASTAR.

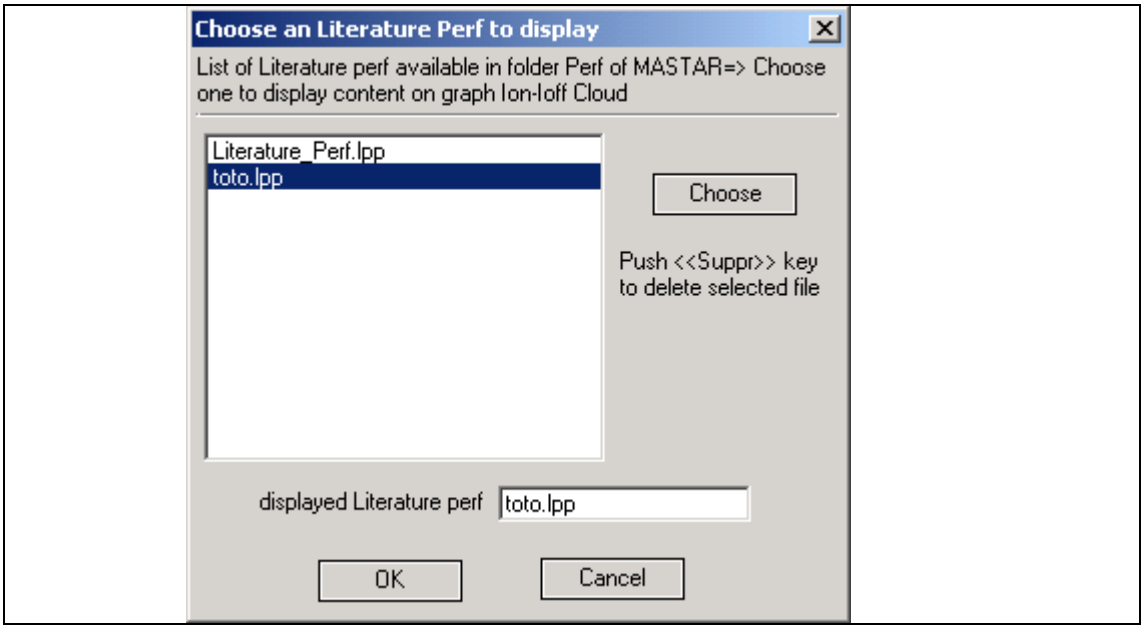

Choose an Literature Perf to display
List of Literature perf available in folder Perf of MASTAR=> Choose one to display content on graph Ion-Ioff Cloud
Literature_Perf.lpp
toto.lpp
Choose
Push <<Suppr>> key to delete selected file
displayed Literature perf
toto.lpp
OK
Cancel

Figure 19: Choosing user defined data files on the Cloud graphics.

The workspaces "Roadmap"

The workspaces "Roadmap" – a global view

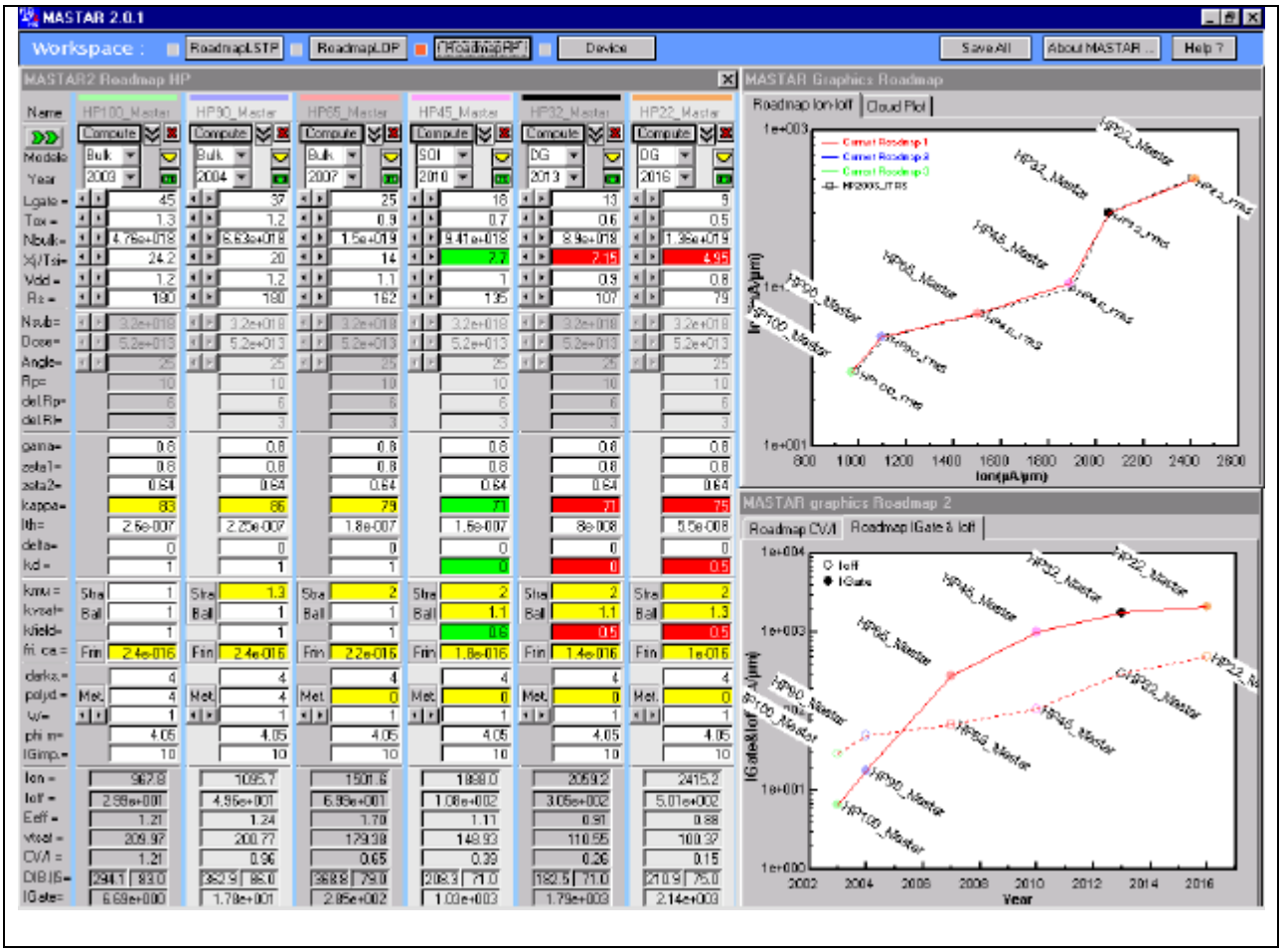


Figure 20: Global view of the workspace "Roadmap".

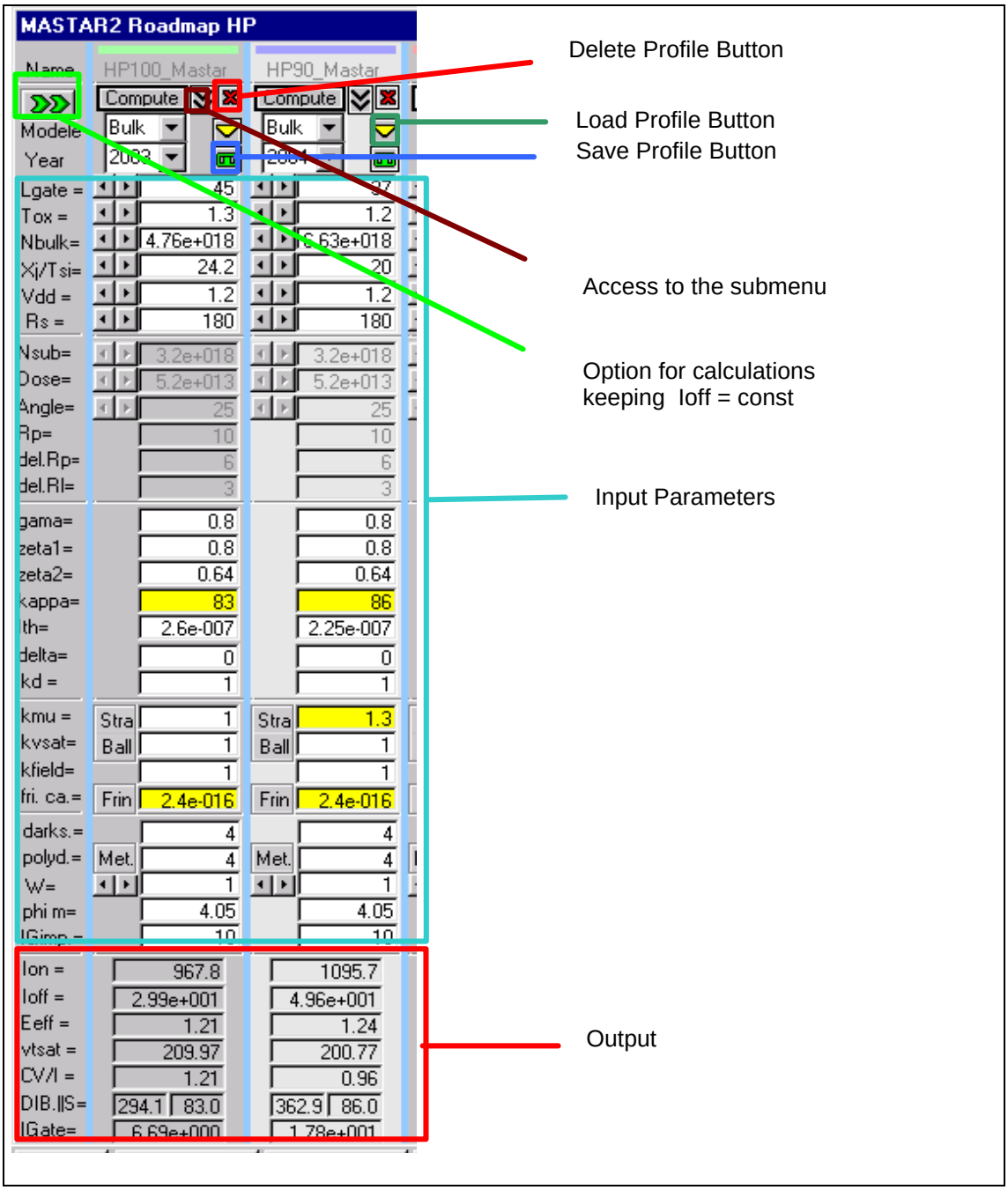


Figure 21: Description of the profile window in the workspace "Roadmap".

The workspaces "Roadmap" have been especially created for the comparison between different CMOS technologies or technological options within a CMOS technology. For this purpose the workspace is subdivided in three different application families, which are: LSTP (Low Stand by Power), LOP (Low Power) and HP (High Performance).

Each workspace is separated in two functional parts: on the left side, up to 6 different profiles can be loaded, visualized and modified independently.

On the right side, two graphics are shown: on the upper graphics, the performance values in terms of Ion-Ioff-data points are plotted. The graphics below shows either

the gate delay or the Igate- and Ioff-values versus the year of introduction as defined on the profile windows.

Loading and modifying profiles

Profile files can be loaded in the window by clicking on the yellow button and by choosing the desired profile file from the list. Once loaded in the window, all input variables can be modified. If you want the changes to be permanent just click on the green button, the profile file will then be updated.

The full menu

The complete option menu associated with a given profile can be accessed clicking on the double arrow symbol, which is next to the compute button.
The following features can be chosen:

Load Profile:	same as the shortcut by the yellow button
Save Profile:	same as the shortcut by the green button
Save Profile As:	saves the profile under a different name
Close Profile:	closes the profile in the corresponding window
Enable Pocket:	activates the Pocket Module inside the profile window
Label Display:	allows the user to change the position of the data label with respect to the data point
Include into:	allows the user to insert a data point into a line

Calculation options and display of the numerical results

On the bottom of every profile column, the basic electrical characteristics are displayed such as Ion, Ioff, Eeff, Vtsat, CV/I, DIBL and Igate. The values are updated whenever you confirm the changes done on an input parameter with the "Compute"-button.
For performance comparisons, you might wish to keep the I_{off}-value constant during the modification of parameters. To do this, click on the button with the green symbol on the upper left side of the window and activate "Keep Ioff constant". In this case, the channel doping and thus the threshold voltage is automatically adjusted to keep the off current constant.

Graphical output

The graphical output of all loaded profiles is automatically displayed on the graphics on the right side. The upper graph shows the Ion-Ioff values either on the conventional Ion-Ioff chart or on a Ion-Ioff cloud chart. Clicking on the right mouse button, you can carry out some modifications on the plot, such as changes in the scaling ("Modify Scale"), and the selection or presentation of the data points ("Load and Unload Plot" and "Create / Modify Plot").
The lower graphics has two presentations: you can choose between a presentation of the gate delay CV/I versus the year of introduction – as specified on top of every profile - and Ioff & Igate versus the year of introduction. Note that you can disable the plotting of the introduction year on the x-axis: just use the right mouse button and deactivate "Enable year". In the graphics window, the data points are now ordered from the left to the right as they appear in the profile frames.

Mastar On-Line Service

If you have any questions or suggestions, please send an e-mail to:

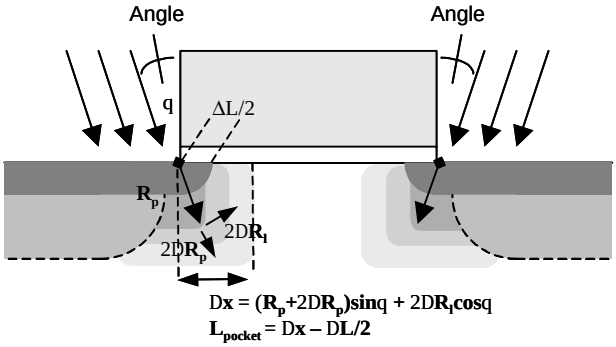
frederic.boeuf@st.com

References

1. T. Skotnicki, G. Merckel et T. Pedron, « The Voltage-Doping Transformation : A New Approach to the Modeling of MOSFET Short-Channel Effects", Electron Device Letters, Vol 9, N° 3, 1998
2. T.Skotnicki , G. Merckel et T. Pedron « A New Punch-through Model based on the Voltage Doping Transformation", IEEE Transaction on Electron Devices, pp1067-1086, 1988
3. T.Skotnicki, G. Merckel et T. Pedron « Analytical Study of Punchthrough in Buried Channel p-MOSFETs » , IEEE Transaction On Electron Device, Vol 36, N°4, 1989
4. T. Skotnicki, G. Merckel et A. Merrachi, «New Physical Model For Multiplication Induced Breakdown in MOSFETs », Solid State Electronics, Vol 34, N°11, pp1297-1307, 1991
5. T. Skotnicki, G. Merckel and C. Denat ,"Triggering and Sustaining of Snapback in MOSFETs", Solid State Electronics, Vol 35, N° 5, pp 717-721,1992
6. T. Skotnicki, C. Denat, P. Senn, G. Merckel and B. Hennion,"A New Analog/Digital CAD Model for Sub-halfmicron MOSFETs", IEDM 1994
7. T. Skotnicki, "Heading for decananometer CMOS – is navigation among icebergs still a viable strategy?" ESSDERC 2000, Invited Paper
8. T. Skotnicki, Encyclopédie Technique de l'Ingénieur, « Transistor MOS et sa Technologie de Fabrication » Cahier E 2 430, février 2000
9. T. Skotncki and F. Bœuf, " Introduction à la Physique du Transistor MOS", EGEM, to be published

Annex A

Illustration of the Pocket Module Parameters



Annex B.

The Mastar Equations (after Refs 6-9)

If K=0, then
$S = \frac{kT}{q}\ln 10\left(1+\frac{e_s}{e_{ox}}\frac{T_{ox\_el}}{T_{dep}}\right)$
else
S=K
	$\log I_{off} = \log(I_{th}) - \frac{V_{th,off}}{S}$
	$Ith = 5\times10^{-7}[A]\frac{W}{L}$
	$Ith\_new = 5\times10^{-7}[A]\frac{W}{L}8\times10^{8}N_{ch}^{-0.4865}\left[cm^{-3}\right]$

$T_{dep} = \sqrt{\frac{2e_s}{qN_{ch}}(2j_F - V_b)}$	$T_{ox\_el} = T_{phys}\frac{e_{SiO2}}{e_{actual}} + D_{ark\_space} + P_{oly\_depl}$
$m_{\text{eff}} = K_{mu}\frac{m_{\text{sr}}m_{ac}}{m_{\text{sr}}+m_{ac}}$	$\text{nMOS}: m_{ac}\left[\frac{\text{cm}^2}{\text{Vs}}\right] = 330E_{eff}^{-0.3}\left[\frac{\text{MV}}{\text{cm}}\right]$ $\text{pMOS}: m_{ac}\left[\frac{\text{cm}^2}{\text{Vs}}\right] = 90E_{eff}^{-0.3}\left[\frac{\text{MV}}{\text{cm}}\right]$
$\text{nMOS}: m_{sr}\left[\frac{\text{cm}^2}{\text{Vs}}\right] = 1450E_{eff}^{-2.9}\left[\frac{\text{MV}}{\text{cm}}\right]$ $\text{pMOS}: m_{sr}\left[\frac{\text{cm}^2}{\text{Vs}}\right] = 140E_{eff}^{-1}\left[\frac{\text{MV}}{\text{cm}}\right]$	$\text{nMOS}: E_{eff} = K_{field}\left(\frac{V_G + V_{th,on}}{6T_{ox\_el}} - 2\frac{V_{FB}+2f_F}{6T_{ox\_el}}\right)$ $\text{pMOS}: E_{eff} = K_{field}\left(\frac{V_G + 2V_{th,on}}{9T_{ox\_el}} - 3\frac{V_{FB}+2f_F}{9T_{ox\_el}}\right)$
$V_{th,on} = V_{th,off} + \Delta$	$V_{gt} = V_{gs} - V_{th,on}$
$C_{ox\_el} = \frac{e_{SiO2}}{T_{ox\_el}}$	$I_{dsat0} = \frac{1}{2}m_{eff}C_{ox\_el}\frac{W}{L}V_{gt}V_{dsat}$
$V_{dsat} = \frac{1}{\frac{1}{L\ E_c} + \frac{1+d}{V_{gt}}}$; $E_c = K_{vs}\frac{2n_{sat}}{m_{eff}}$	$\text{d} = K_d\frac{\text{K}_\text{B}}{2\sqrt{2j_\text{F} - V_b}}$

$K_B = \frac{qN_{ch}T_{dep}}{C_{ox\_el}\sqrt{2j_F - V_b}}$	$I_{dsat} = \frac{I_{dsat0}}{1 + \frac{2R_s I_{dsat0}}{V_{gt}} - \frac{R_s I_{dsat0}}{V_{gt} + L_{el}E_c(1+d)}}$
Dark_space ≅ 2-4 Å EOT (electrons) et 3-5Å EOT (holes)	Poly_dep ≅ 4Å EOT (n^+-gate), 6Å EOT (p^+-gate), $EOT = T_{phys}\varepsilon_{SiO2}/\varepsilon_{actuel}$
$I_G = \frac{1}{2}\Delta LW \times ae^{\left(bV_g^2 + cV_g\right)}e^{-dT_{ox\_phys}}$ Parameters for J_g : a=1.44.10^5 A/cm², b=-4.02 V^{-2}, c=13.05 V^{-1}, d = 1.17 $Å^{-1}$	